OPERATIONAL SYNTHESIS FOR RECONNAISSANCE AND SURVEILLANCE

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ABSTRACT

Military Systems Experimentation Branch and Land Operations Division have been examining the utility of agent-based distillations (ABD), and the method of Operational Synthesis, in assisting existing operational analyses of future warfighting concepts. The case study chosen was a wargame (the Headline Experiment 00 (HE00)) that examined the concepts for Manoeuvre Operations in the Littoral Environment (MOLE), including the role that reconnaissance and surveillance (R&S) has in enabling a force to achieve its mission. Additional analyses were then performed using closed loop simulation and ABD

The wargame demonstrated the critical reliance that light and highly mobile forces have on R&S. The dependence was most apparent when conducting manoeuvre operations at high tempo while attempting to mass effects on an enemy while remaining at "arms length" from his strengths. The effectiveness of R&S was also found to degrade as terrain complexity increased.

This paper describes the initial constructive wargame, and the closed loop simulations, system dynamics model and ABD used to represent these future forces. The three techniques used a common analytical aim to focus their application and a common scenario to allow comparison of outcomes. The results demonstrate how these tools can analyse future warfighting concepts from a number of perspectives as well as generating both confidence in "intersecting insights" and an increased span of results. Finally, the paper comments on how these tools may be employed more effectively within an analytical framework to support military experimentation.

1. Introduction

Operational synthesis is an analysis method initiated by the US Marine Corps Combat Development Command to explore new and novel war fighting concepts by the application and integration of existing tools and techniques [1]. However, the application of multi-faceted hierarchical analysis techniques to robustly investigate emerging war fighting concepts is not new, and in fact it has long been a principle of military operations analysis techniques [2]. Operational synthesis is novel in that it attempts to integrate across a range of simulation tools and operational analysis techniques that includes a class of models known as agent-based distillations (ABDs).

ABDs are simple, easy to use, transparent simulations that abstract away from the traditional detailed physics modelling of battlespace entities and instead focus on the personalities and non-physical interactions of the entities within the simulation. In general the current suite of military simulations do not adequately represent these non-physical human aspects [3]. ABDs can begin to satisfy this requirement, but at the expense of detailed physical modelling.

The uncomplicated nature of ABDs makes them useful for the rapid investigation of a large problem space through a process known as data farming [1] to identify significant trends and high payoff areas for more focussed analysis. Data farming also allows extensive parameter excursions to be performed, both in terms of variations in platform capabilities and tactics (behavioural characteristics), from the baseline scenario. This then enables multi-variable sensitivity analyses to be performed to explore any non-linear behaviour and synergies in the system. The farmed data can also be used to perform statistical analyses to test the significance of the properties observed.

Their limitation is that they are not at a sufficient level of fidelity to inform capability development decisions with any degree of confidence. Hence the linking of ABDs to higher fidelity analysis techniques at multiple stages in an analysis methodology will provide a greater degree of analytical rigour than ABDs alone. The general elements within Operational Synthesis are illustrated in Figure 1.

This paper will investigate an operational synthesis case study of reconnaissance and surveillance (R&S), used to support the Army Experimental Framework, to highlight issues for the application of the technique. The use of a number of tools and techniques will be described within the operational synthesis process, including a Janus driven command post exercise (CPX) wargame, CASTFOREM simulation, ABDs and system dynamics analysis techniques. The ABD modelling was conducted during the 4th Project Albert Workshop, which was held in Cairns, Australia from 6 – 10 Aug 01 [4].

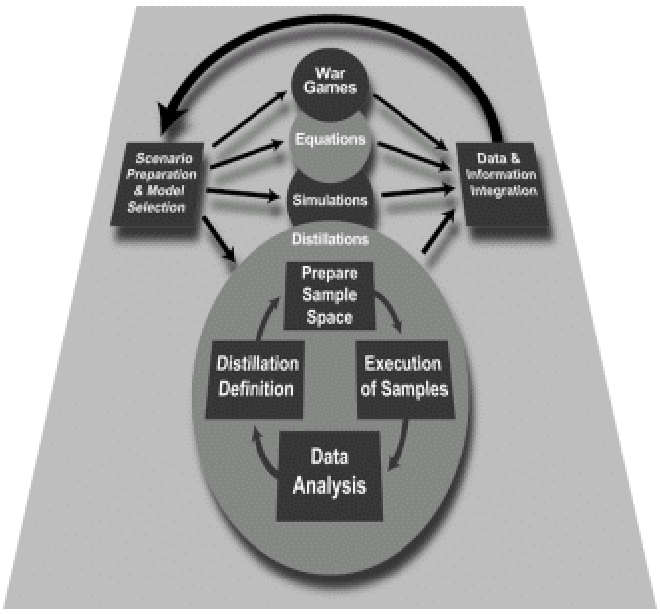

Figure 1: Elements of Operational Synthesis (taken from [1]).

1.1 Background

The Army Experimental Framework (AEF) supports the Army's continuous modernisation program by providing an analytical framework to define, test and refine capabilities and concepts [5]. The AEF 2000 (AEF00) examined future force structure options and concepts for a mechanised task force within the Military Operations in a Littoral Environment (MOLE, see Appendix A.1) concept. AEF00 continued a program of experimentation from the Restructuring The Army (RTA) program of 1997 to 1999 that initiated and refined many of the experimental processes embodied in the AEF00 program [6].

The Headline Experiment 2000 (HE00) was the major analytical event within AEF00. The aim for the HE00 was to assess the war-fighting concept and structure for EXFOR1, an Enhanced Combat Force (ECF) heavy/medium Task Force (TF) for the Defence of Regional Interests (DRI) out to 2016, in order to inform force development [6]. The method used was a two level Command Post Exercise (CPX) driven by the Janus Wargame. Data on the performance of the forces being examined was collected using a variety of automated and observational techniques.

2. Models

2.1 Operational Synthesis

The goal of Operational Synthesis is [1] "to use the individual tools for what each is good for, and to put them all together in a way that synthesises the wealth of information and knowledge which is gained by utilising each of them." We have had some experience in this process, through RTA and the Headline Experiments and post experiment analysis, by synthesising the information generated by a wargame (Janus) and a higher-fidelity simulation (CASTFOREM). The primary focus of the current case study is to supplement these results with those of an ABD by using a common scenario and parameter excursions to establish a shared frame of reference amongst the models.

Our approach was to think of the information generated by each tool in terms of a Venn diagram (Figure 2, and Figure 3). The synthesis component of Operational Synthesis is then represented in terms of regions of information intersection and union within the concept frame of reference. Intersecting regions will be used to provide increased confidence in the insights provided by the tools, or to discover conflicts that must be further investigated. The union of non-intersecting regions provides complementary (but non-correlated) information on the concept under investigation. This latter region will largely be generated by the ABD through the process of data farming.

Operational synthesis can be used to support concept exploration (Figure 2) in which large areas of the frame of reference are investigated at a relatively low fidelity in order to develop a force concept and identify its critical vulnerabilities and most appropriate concept of operations [7]. The aim is to gain insights into where the concept is most sensitive to parameter variations manifested as non-linearities that could represent vulnerabilities or combat multipliers for the force. These regions can then be explored in greater detail during a concept validation phase (Figure 3). During concept validation the effectiveness of the concept is evaluated at increasing levels of fidelity to produce tasks, doctrine and equipment options for the force. In both Figure 2 and Figure 3 the size of the circles represents the scope of the analysis performed by the tool while the darkness represents the fidelity or depth of analysis.

In the case of concept exploration the tools intersect in small regions that represent the models synthesising a portion of the concept. This synthesis occurs through the use of common input data, such as the scenario or system characteristics, in an attempt to replicate trends in results and add confidence to the intersecting regions. This in turn adds confidence to the non-intersecting but complementary regions of analysis because of the mutual validation of a portion of the model. If the results from planned intersecting regions do not correlate then there is either a reduced confidence that the tools are situated in the desired area of the concept frame of reference or the fidelity of the tools is such that it has revealed an unexpected, yet potentially valuable, result. These cases will be highlighted later in the paper.

Concept validation (Figure 3) is a specialised case of concept exploration in that all tools intersect in an increasing limited, yet highly critical, area of the concept frame of reference. The aim is to gain maximum confidence in a region of the concept frame of reference through the focussing of tools with increasing fidelity. Implied in this description is that lower fidelity tools have greater scope than higher fidelity tools.

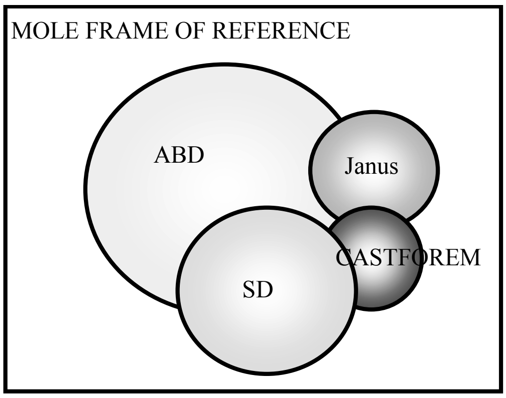

Figure 2: Operational Synthesis – Concept Exploration.

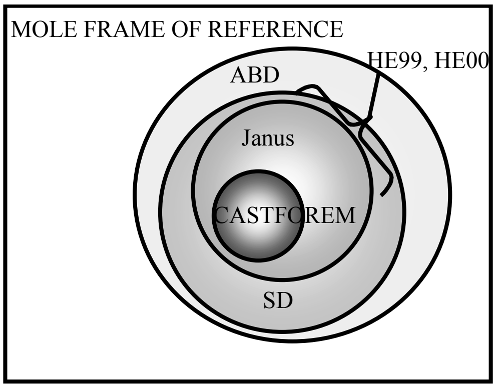

Figure 3: Operational Synthesis – Concept Validation.

2.2 Analytical Tools and Techniques

There are a wide variety of modelling tools available and their fidelity can be classified using a number of criteria. Hence describing what is a high fidelity tool is application and context dependant. Table 1 gives a comparison of the relative fidelity of the techniques used in this case study. The comparison is based on the author's experiences with these tools. Although field trials and seminars were not used in this application they have been included as they are candidates to be used in an operational synthesis application.

Table 1: Characteristics of analytical tools and techniques.[1]

Fidelity		CPX (Janus)	CASTFOREM	ABD	SD	Field Trials	Seminar
Modelling	**Physical**[2]	**H**	**H**	**L**	**L**	H	L
	Behavioural	H	M	M	L	H	L
	Environment	M	M	L	L	H	L
Results	Qualitative	H	L	H	M	H	M
	Quantitative	H	H	L	L	H	M
	Scope	M	L	H	M	H	H
	Optimisation	**L**	**M**	**H**	**H**	L	L
	Cost	M	M	L	L	H	L

The analytical focus of this case study is the balance of capabilities for reconnaissance and strike assets within EXFOR1. Put in the terms used in the previous section, the analytical frame of reference is the optimisation of the system through the application of a concept validation framework of analytical tools. The desired outcome is an optimal mix of capabilities. The traditional method of concept validation would be through the application of tools with increasing physical modelling fidelity (Figure 3). Moving from the lowest to highest physical modelling fidelity in Table 1 would lead to ABD and system dynamics focussing the application of tools such as a CPX and CASTFOREM. In this case the frame of reference is the application of increasingly higher fidelity tools to the physical aspects of the concept. However the highest fidelity tools, Janus and CASTFOREM have only a very limited optimisation capability of quantitative results. The results, although very detailed, are only of limited scope covering just a few instances of the parameter space. Interpolation between, and extrapolation beyond those points is a qualitative process, and hence optimal results cannot be accurately identified, only trends in performance interpreted from limited samples.

An alternate approach being proposed for concept validation is to follow the conventional method above when scheduling the application of the tools, that is low fidelity physical modelling focussing the high fidelity physical modelling. But when conducting the analysis, reverse the order in which the results are notionally considered, that is low fidelity optimisation tools (CPX and CASTFOREM) informing the interpretation of higher fidelity optimisation tools (ABD and system dynamics) as shown in Figure 4.

The aim is to find an optimum by searching the results related to the largest area possible of the concept frame of reference, in this case provided by the formal optimisation tools (high fidelity Optimisation in Table 1). Hence the ordering of results is from a CPX followed by CASTFOREM and finally results from system dynamics and ABDs. The philosophy is to use the wider scope of the results from the high fidelity optimisation tools to interpolate and extrapolate the results from high fidelity modelling tools. In that way the high fidelity modelling tools provide the validity while the optimisation tools provide the optimum result. In this case the capabilities of the tools is driving the application but the analytical aim is driving the interpretation of the results. Typically the order in which the tool is applied is the order in which results are considered.

[1] High fidelity (H), Medium fidelity (M), Low fidelity (L)
[2] Detection, engagement and movement

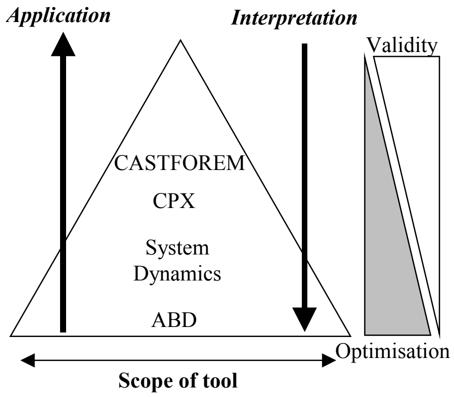

Figure 4: Application of tools and interpretation of results. (Adapted from [8])

It is postulated that there is no fixed order in which to apply the tools in all cases, instead it is dependant on the analytical aim (frame of reference) and stage of concept development (exploration or validation) of the problem at hand. In addition there should be a distinction made between the order the tools are applied to the problem and the order in which results are notionally considered.

2.2.1 CPX Wargame

The majority of insights drawn out of the HE00 were due to scenario events that were played out in the Janus wargame. However it was the linking of Janus, through a command support system, to the geographically separated battlegroup and brigade headquarters that created an information rich synthetic environment that generated many of the meaningful results from the HE00. The strength of the technique was that it represented the non-physical human aspects of warfare by immersing the human players in the synthetic environment at the various levels of command from the brigade to the platoon. Thus it was the utility of embedding Janus into a CPX linked through a real world command support system that provided many of the results and not Janus as a stand-alone tool.

At the conclusion of each scenario an after action review (AAR) was held. In attendance were the players from both sides and analysts. The function of the AAR was to draw together quantitative and qualitative observations to generate insights. The insights into the application of the MOLE concept from the AAR formed the results from the HE00 and the basis for further analysis using other tools and techniques.

The Janus wargame itself provided the dynamic force on force adjudication of combat and manoeuvre. Janus as used in support to the HE00 was constrained to a brigade sized forces and a play box of approximately 170 x 170 km. Computer entities controlled by human interactors were played as single systems in the case of high value assets and aggregated as pairs for other assets.

A limitation of the Janus driven CPX synthetic environment construct is that Janus is an attritionalist wargame that does not represent many of the non-physical aspects of the battlefield such as the cyber and electromagnetic domains. Although some of these effects were introduced into the HE00 by physically disrupting the flows of information between levels of command, the results were not seamless and did not capture the subtle degradation of a force subject to such influences. In addition it was difficult for Janus to model many of the advanced sensor and weapon system effects that the MOLE concept is predicated upon due to data and algorithm limitations [6]. Despite these limitations the emersion of the normal command and control (C2) system provides a useful analytical environment to explore some human performance aspects of manoeuvre warfare, such as surprise, tempo and, to a limited extend, shock.

2.2.2 CASTFOREM

CASTFOREM is a closed loop, event driven, stochastic simulation of the combined arms battle. The model is used by the US Army's TRADOC Analysis Center (TRAC) as its primary brigade and below entity level analytical simulation. CASTFOREM utilises appropriately validated databases describing weapon effects and platform protection. Its primary role has been for investigating future force concepts at the medium to high levels of conflict. Widespread acceptance of the model and its algorithms in the US Army affords it a high degree of validation. It has been developed and used for analysis in RTA Phase 1 trials, in support of RTA Phase 2 and AEF [6].

CASTFOREM models each individual soldier, vehicle and weapon system, with the ability to incorporate extensive data on systems. The model is suited to studies of alternative organisational structures, equipment mixes, tactics and doctrine as well as analysis of unit modifications or performance parameters. There is a significant workload involved in the development of a scenario, with lead times of 4-18 months depending on the level of detail required and resources available.

CASTFOREM models the reconnaissance elements of battle through the integration of the sensor and C2 systems. Unlike Janus, CASTFOREM does not have human players who interact with the simulation. Instead all relevant courses of action are coded into the model using an expert system. The relevant commander's decisions and appropriate actions were subsequently simulated, depending on the nature of the information presented through the SA databases[3]. The advantage of CASTFOREM over Janus is that multiple (but still limited) parametric excursions of the simulation can be examined once the basic scenario is developed.

The reconnaissance aspects within CASTFOREM are affected by the interaction of platform characteristics (sensors and platform signatures), force mix, tactics, C2 system and environmental complexity. CASTFOREM allows simulation of all these factors to varying degrees of fidelity making it a suitable tool for investigation of the system as a whole within a specific scenario context. [6]

However, a significant limitation in the simulation of reconnaissance in CASTFOREM, as it is for Janus, is the availability of accurate performance data for the combat systems. Hence, in analysis, it is often best to draw comparisons between scenario alternatives and allow relative judgements to be formed, rather than placing confidence solely on the quantified data obtained.

2.2.3 System Dynamics

System Dynamics is a technique that allows a time variant system to be analysed, recognising the major influences and interactions that affect the system's dynamics such as feedback of resources and information. It was first developed by J. Forrester [9], and has since found widespread use throughout industry and academia as a useful and insightful methodology. Various studies have been conducted into defence problems using system dynamics. Coyle [10] has conducted a survey that highlights many aspects of the methodology in this context.

Essential to System Dynamics is the influence diagram, a visual representation of the system where the influence that each element of the system has on other elements is presented. The flow-on effects from any changes may also be visible. Flow-on effects are largely identified through 'feedback loops', where a set of influences form a continuous loop in the diagram which, in effect, can amplify an aspect of the system whether the loop is positive or

[3] This represents a level of SA whereby positional information is processed through a commander's decision process to generate reactions. The deduction of an enemy's intent is not explicitly modelled.

negative. This allows the significant features of the system to be easily identified, allowing not only the study of the system, but suggestions as to how to it might be improved to be readily identified.

In alignment with the hypotheses described in section one above, a system dynamics study was based on the reconnaissance and strike aspects of the force. The key focus of this investigation was the ratio of asset types (reconnaissance and strike) required in the force balance.

The model was able to allow the transfer of reconnaissance assets to strike assets and vice versa but an asset could not be in a reconnaissance and strike role simultaneously. There was one significant limitation to this approach. In reality most assets have dual (concurrent) reconnaissance and strike capability, allowing strike assets some level of target acquisition capability and reconnaissance assets some degree of lethality. This was not modelled, which has implications described in the results. Another limitation was the lack of appropriate combat system performance data. This study focuses on the methodology and how it can be applied in conjunction with other models. The study described was simplistic, included to illustrate the process.

2.2.4 ABD

Agent based distillations (ABD) are low-resolution abstract models, used to explore questions associated with land combat operations in a short period of time. Being agent based means that only simple behavioural rules need to be assigned. This is generally achieved by assigning 'personalities' to the agents by way of relative weightings to various elements on the battlefield (friendly and enemy agents, notional 'flags', terrain features, etc) and a linear penalty function to determine the entity's next move. Various 'meta-personalities' can also be assigned which moderate the agent's default personality if certain threshold constraints are exceeded from time to time. Thus the scenario is much less scripted than that of CASTFOREM, the idea being to allow a focusing of thought on the essential elements of the systems, which typically is the dynamic interaction of entities on the battlefield.

The ABD modelling was conducted using the ISAAC model [11] in conjunction with the Maui High Performance Computing Center for the data farming. For the baseline scenario the Blue force consists of 10 high lethality, low protection strike agents and 5 reconnaissance agents, while the Red force consists of 25 high lethality, high protection Red agents.

The strike agent has a superior sensor range than the Red agents but have relatively poorer weapon characteristics. The reconnaissance agents are equipped with 'spotlight' type sensors and are positioned forward of the strike agents. Their task is to survey the positions of the Red agents and communicate detections back to the strike agents. The strike agents move towards the Red agents based on the information provided by the reconnaissance agents, and thus relies on good communications. Tactically, they will engage the Red agents once a numerical advantage is achieved. Red is effectively static, defending its centre of gravity until Blue units are detected at which time they actively pursue them with an intent to engage. Whilst Red does not require a numerical advantage to attack Blue, they do require at least as many Red agents nearby as there are Blue units. These tactical behaviours are modelled in ISAAC as a simple system of attraction-repulsion weightings.

3. R&S Scenario

Observations made during HE00 showed that the Experimental Force (EXFOR1) relied heavily on reconnaissance at the tactical level for collecting and maintaining their situation awareness (SA). It was stated in Brennan et al 2001 [6] that "the military judgement collected in the seminars confirmed that the Light Armoured Vehicle (LAV) basis for the force places a heavy reliance on situation awareness (SA) in order to manoeuvre around enemy strengths or to mass effects to defeat the enemy in given locations". It was noted by the Senior Officers Study Period (SOSP) in their brief to CASAG that "…The experiment confirmed that EXFOR1's manoeuvre strengths in open terrain would be nullified by the characteristics of complex terrain. The force no longer had the ability to remain beyond 'arms length' of the enemy" [6]. These observations indicated that the R&S issue was fundamental to the performance of a force conducting manoeuvre operations. Further details of the EXFOR1 force construct can be found in Appendix A.

The analytical focus of the study has hence been to look at the balance of capabilities required to achieve the R&S functions and how these capabilities have enabled EXFOR1 to fulfil its mechanised strike functions across a range of environments. The investigation has been used as a vehicle for exploring the issues surrounding operational synthesis with the analytical outcomes being considered indicative rather than definitive of the actual concepts.

3.1 Scenario Characteristics

In order to investigate the balance of capabilities within EXFOR1 a scenario was chosen from the HE00 unit level Janus wargame runs for more detailed analysis using a variety of analytical tools. The scenario was chosen to stress EXFOR1's capabilities, in particular its reconnaissance and close combat capabilities. The scenario was used to bound the range of environments and threats that the experimental force was to be tested within and against. The scenario had the following characteristics that made it suitable for further investigation.

- The scenario placed emphasis on the reconnaissance phase prior to the close battle.
- The scenario culminated in close combat, providing a combat test of the force.
- The terrain covered in the scenario was characteristic of the littoral environment.

In general terms, the EXFOR1 scheme of manoeuvre initially involved a light reconnaissance combat team conducting a reconnaissance / counter-reconnaissance operation supported by brigade level assets such as UAVs and indirect long-range fires against a similar size enemy force. Following the reconnaissance phase a combined arms battle group closed with a defensive enemy of a similar size resulting in a deliberate close battle. The convention used to describe the forces in this paper is Blue for EXFOR1 and Red for the enemy.

The scenario is represented abstractly in Figure 5 so as to emphasise the depth of forces in contact and lethality of the effects applied in each phase. The diagram also captures the linear nature of the scheme of manoeuvre developed during HE00 and subsequently represented in the analysis.

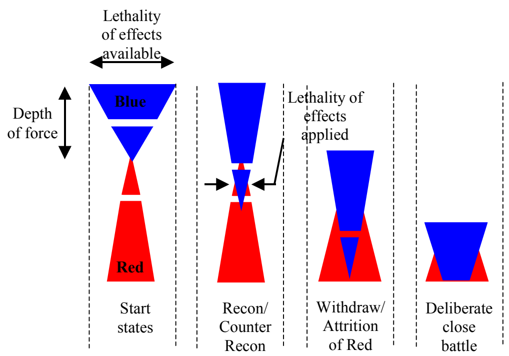

Figure 5: Scenario description.

3.2 Hypothesis

Given the proposed heavy mechanised functions built into EXFOR1 (described in Appendix A), a working hypothesis relating battlefield survivability and the effectiveness of RSI was proposed. This was that; *the denial of an area by light armoured forces, through the process of domination by fires, is dependant on battlefield survivability that in turn has a critical dependence on the information generated through the RSI function*. It was also postulated that an appropriate OPFOR course of action in response is to deny the RSI function in addition to reducing EXFOR1 battlefield survivability. An influence diagram (Figure 6) describes the postulated relationship that was used to focus the development of aspects of the analytical tools.

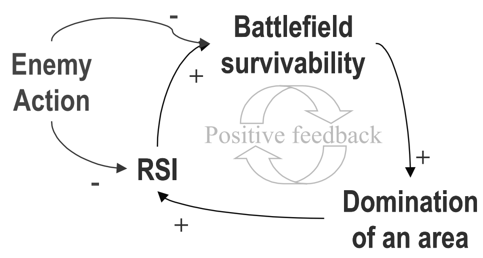

Figure 6: Postulated relationship between battlefield survivability and RSI.

The generation of data for analysis focussed on varying the reconnaissance battle and terrain complexity while measuring the success or otherwise by observing the performance of EXFOR1 to dominate an area utilise indirect fires and survive the close battle.

Broadly speaking the capabilities of the force can be quantified at two levels:

1. at the platform performance level, and
2. unit (Battle Group) effectiveness as a whole.

The results described in this paper only deal with the unit level.

4. Experiment

A number of ORBAT Excursions and a terrain Alternative (Alt) derived from the baseline scenario described above were investigated in CASTFOREM, ISAAC and the systems dynamics model. Janus was not used to investigate these excursions or alternatives due to the overheads in conducting a wargame. The excursions are listed in Table 2.

Table 2: Excursions from the Baseline.

	Terrain Complexity	
ORBAT	**Baseline**	**Alt1**
Baseline	Open	Light
A. Indirect Fire	Open	Light
B. More Recon	Open	Light
C. Traded Recon	Open	Light

4.1 Alternative 1

In CASTFOREM, the effect of terrain complexity was modelled as a decrease in the probability of detection as the vegetation density increases from open to light. It was assumed that there was no change in tactics, such as dismounting troops to conduct reconnaissance. In ISAAC, cookie cutter detection is assumed, so that the sensor range was reduced. The terrain complexity variable was not examined in the systems model.

4.2 Excursion A

Increased indirect fire capability was modelled by assigning a lethality capability to the reconnaissance agents in ISAAC, by relaxing the targeting thresholds for indirect fire in CASTFOREM and by increasing the maximum allowable number of strike assets in the systems model.

4.3 Excursion B

To test the impact of additional reconniaissance assets the number of reconnaissance agents was increased in ISAAC, doubled in CASTFOREM and increased in the systems model.

4.4 Excursion C

Strike and reconnaissance assets were traded one for one in ISAAC, CASTFOREM and the systems model to test the asset trade off.

5. Results

5.1 CPX Wargame

The results obtained from the CPX wargame phase of HE00 are mainly qualitative insights produced by the AAR process. They have been used to focus the development of other analysis techniques within the operational synthesis methodology. The insight of relevance to this R&S case study was that EXFOR1 was shown to be vulnerable to close combat. This vulnerability is amplified as terrain complexity increases.

5.2 CASTFOREM

The CASTFOREM results in Table 3 shows that in the Baseline scenario Blue have a slight advantage as represented by the LER. In Excursion A both the Red and Blue losses increase slightly over the baseline with additional indirect fire assets. However when the number of reconnaissance assets is doubled in Excursion B, Blue inflicts more losses on Red while their Blue losses remain the same as the Baseline. Overall they still only have a slight victory. Comparing Excursions A and B suggests that, in this scenario, an investment in reconnaissance and target acquisition has a higher payoff that an investment in indirect fires.

In Excursion C where the reconnaissance assets were traded off for strike assets, there was a similar result to the baseline in terms of losses to both sides and the overall number, resulting in a slight victory for Blue. In this case the model indicated that the force was not sensitive to trading off some strike assets for reconnaissance assets.

However in Alternative 1, where Red experience a decrease in losses and Blue an increase due to the increase in terrain complexity, Blue suffer a slight defeat in the baseline. In Excursion A and C Blue are able to achieve a slight advantage, hence additional indirect fires or higher levels of reconnaissance (traded for strike in Excursion C) go part way to negating the impact of increased terrain complexity. By far the most interesting result is the impact of additional reconnaissance in Excursion B that leads to a significant victory in light terrain. This result would suggest that additional reconnaissance in combination with the baseline strike assets is a decisive advantage in light terrain. Such a result, while significant in the context of the other results, is the subject of further investigation using higher fidelity terrain models in CASTFOREM.

5.3 System Dynamics

The system dynamics results for the initial baseline case of the model, shown in Table 3, indicate that Blue suffer a significant loss. This is as a result of the modelling limitation that once the surveillance assets are depleted, blue cannot target any more red assets, despite the large number of strike assets remaining. Hence all assets are unable to engage and are subsequently destroyed. In reality, this would occur to a lesser extent, as most strike assets have some targeting capability. However, as the model does not have this capability the effect is magnified and results in a binary event, i.e. overwhelming victory or loss. The binary result is repeated in Excursions A, B and C with Blue being successful only when additional reconnaissance or strike assets become available.

While these results highlight the importance of the surveillance capability, especially the utility of multi-role assets, it is the methodology that is emphasized. System dynamics allows the examination of the problem in conjunction with other studies, and the model may be varied to suit study requirements.

5.4 ABD

In Excusrion A the reconnaissance agents were given a lethality (to simulate indirect fire) and added to a fixed number of strike agents. When the number of reconnaissance agents was varied from 1 to 10 the number of Red losses increases linearly, as would be expected with the increased firepower. At the same time the number of Blue losses decreases linearly, again this is an intuitive result. When reconnaissance agents and strike agents were traded in Excursion C, the number of Red losses was very high and virtually constant regardless of how many strike agents were traded for reconnaissance agents.

This could be explained by thinking of the trade of reconnaissance agents (with lethality to simulate indirect fires) and strike agents as a trade of firepower for similar firepower. The limitation of the modelling was that the associated time delay to call in indirect fires (and the resultant decreased in effectiveness) was not modelled. However the number of Blue losses quickly reduces to almost zero as the number of reconnaissance agents increases. This again is intuitive because we are trading relatively unprotected strike agents for highly stealthy, and hence survivable, reconnaissance agents.

In Excursion B the number of Red losses appears independent of the number of reconnaissance agents for both the open and light terrains. However, the number of Red losses almost doubles in light terrain. It appears that this may occur because Red does not have any stand off distance in the light terrain. They have a sensor range of four and are unable to retreat from Blue before they are fired upon as both sides have a firing range of four. Blue is unaffected by this stand off problem as their sensor range in light terrain is seven, giving them a sensor overmatch due to their postulated superior technology. The curves showing Blue losses in Figure 7 indicate a somewhat counter-intuitive result, being that adding reconnaissance agents increases the number of Blue losses. This result is repeated in both open and light terrain. However, given the earlier result of there being more Red losses in light terrain, it is reasonable to expect that there would then be less Blue losses in light terrain, as the graph indicates.

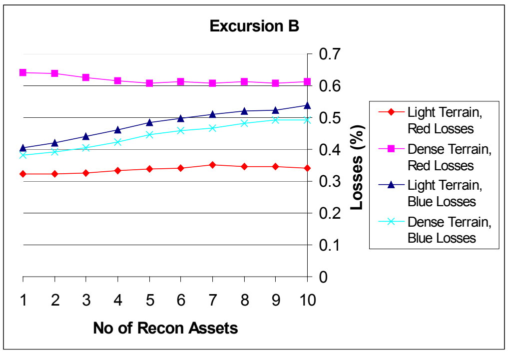

Figure 7: Percentage Losses for Excursion B.

The light terrain case of Excursion C shows that there may be some form of compromise required when deciding whether to trade strike for reconnaissance. As the number of strike agents traded increases the number of Red losses decreases (which is undesirable) however the number of Blue losses also decreases (which is desirable). This raises the question as to which MOE is more important. If both are equally important then the LER could be considered. The results for the open terrain case show very few losses for both sides. This may suggest that the increased level of awareness from both sides resulted in very few engagements.

Table 3: Comparison of Blue success across Excursions and Alternative as indicated by the Loss Exchange Ratio (LER)[4,5].

Blue Success / Failure	Terrain Complexity					
ORBAT	**Baseline**			**Alt1**		
	SD	**CAST**	**ABD**	**SD**	**CAST**	**ABD**
Baseline	☒☒	☑	☒	N/A	☒	☑☑
A. More Indirect Fire	☑☑	☑	☑	N/A	☑	☑☑
B. More Recon	☑☑	☑	☒	N/A	☑☑	☑☑
C. Traded Recon	☒☒	☑	☒	N/A	☑	☑☑

6. Summary

6.1 Comparison Between Models

Table 3 collates the results from the system dynamics, CASTFOREM and ABD models for the various Excursions listed in Table 2. Since the system dynamics model generally simulates the battle out to when one side is clearly in favour, the comparison here is in a binary sense. That is, whether the models both predict a Blue (or Red) advantage (irrespective of magnitude).

The comparison between the system dynamics and CASTFOREM models shows some correlation between the results for Excursions A and B in that Blue is successful in these cases. The trend that the system dynamics model indicates is that additional assets (either reconnaissance or strike) tip the balance of the system in favour of Blue. For the other two cases (baseline and Excursion C) the system dynamics model shows that keeping the overall number of assets constant and trading off between asset types without increasing the overall number has a negative outcome for Blue. However CASTFOREM indicates there is little change between the cases. This comparison highlights how models with lower fidelity physical modelling, though giving different results, can guide the application of models with higher fidelity physical modelling. In this case the system dynamics models indicate that CASTFOREM should perform another iteration to investigate the addition of assets beyond the current excursions since this appears to give Blue an advantage.

[4] LER is the ratio of Red Losses to Blue Losses.

[5] ☑ Slight Blue victory (1.0 < LER < 1.2)

☑☑ Significant Blue victory (LER > 1.2)

☒ Slight Blue loss (0.8 < LER < 1.0)

☒☒ Significant Blue loss (LER < 0.8)

The second, and more interesting comparison is that between the CASTFOREM and ABD models. In particular, we focus on the predicted effect that terrain complexity has on the outcome. With CASTFOREM, the model suggests that increased terrain complexity has a positive effect for the Red force in the Baseline, a result supported by the SME opinion during the CPX wargame. That is, the effectiveness of the Blue force, which relies heavily on its enhanced SA for survivability, is degraded in light vegetation. However in the Excursions A, B and C Blue are as successful, if not more successful, in light terrain. In these cases either additional reconnaissance or strike assets are provided through an increase in total numbers (Excursion A and B) or a tradeoff with strike assets (Excursion C). The greatest benefit appears to be the provision of additional reconnaissance assets in light vegetation.

The ABD model results suggest a similar positive trend in going from open to light vegetation, that is the LAV-based Blue force can be successful when either additional reconnaissance or strike assets are provided through an increase in total numbers (Excursion A and B) or a tradeoff with strike assets (Excursion C). A point of departure in the correlation of trends is in the Baseline where CASTFOREM suggests Blue’s performance degrades and ABDs suggest it improves in going from open to light.

This point of departure between the model’s results should be viewed as a positive characteristic, in that it forces the analyst to examine the potential causes for these variations in effect. As mentioned above, for the ABD model, the effect of increased terrain was to decrease the sensor range of the Red agents such that it was equal to their weapon range. Thus Blue strike agents hold a sensor and weapon range overmatch and a lethality undermatch in the open and light cases. A sensor range overmatch was assumed in light vegetation due to the forces superior sensors. The difference between the open and light cases is that Red no longer has a buffer range between when they can detect and when they can engage in the light case. The Red sensor and weapon range being equal has given Blue a significant advantage although the exact mechanics is not fully understood and requires further investigation.

It was somewhat surprising to the authors that this translated into such a negative effect for the Red agents, given their relative lethality superiority (in both weapon effectiveness and size of force). This suggests (but should be tested with higher fidelity modelling) that it is still important for a heavier force to maintain a buffer in which they can manoeuvre in order to defeat additional Blue assets.

6.2 Conclusions

The process of operational synthesis has provided some insights into the balance between reconnaissance and strike roles within EXFOR1 as hypothesised in Section 3 and Figure 6. In terms of balance of forces an investment in reconnaissance appears to increase the forces battlefield survivability as indicated by the forces LER in this case study. Of greater significance is the impact of moving from open to light terrain on the outcome. When the results from the models were correlated they suggested an investment in reconnaissance or additional strike assets can lead to Blue force being more successful as terrain complexity increases. However analysis from HE00 suggests that this trend would not continue into dense terrain if the same tactics were maintained. As a result the size of the terrain parameter excursion in the tools was not large enough to synthesis this potentially significant result. The use of LER as the main measure restricts the comments that can be made on EXFOR1’s ability to dominate an area, except to say battlefield survivability is a precondition for domination of an area and an increase in reconnaissance improves survivability based on current analysis.

The operational synthesis technique currently relies on the ‘weak linking’ of models and simulations by using the same scenario to establish a common frame of reference and the users knowledge of the tools and problem domain to perform qualitatively comparison of the results. The experimental aim of this case study was to conduct a concept validation study to optimise the EXFOR1 force mix for a specific scenario. The system dynamics and ABD models did not intersect with CASTFOREM and Janus (Figure 8) as is desired for system test (Figure 3). The main factor in this non-intersection was the limitations of the system dynamics model in representing the integral target acquisition capability of strike assets. In the case of ABDs it was the limitations in modelling strike assets but specifically the absence of a time delay for calling in indirect fires that gave Blue an unrealistic advantage. In this case the strike asset parameter could not be varied. The terrain density limitation highlighted above (in CASTFOREM and ABDs), was a case of not varying the parameter over a large enough range. Consequently it is doubtful that the correlation in results discussed in the previous section are a consequence of intersection of results (Figure 3) but instead similar trends resulting from the weak linking of the models (Figure 8).

The failure to identify critical parameters and parameter ranges does not mean it is necessary for ABD and the system dynamics models to have the same modelling fidelity as Janus or CASTFOREM but instead they need to have a representation of the critical parameters that can then be varied across similar ranges. In this study the critical parameters only came to light once the results for all the models were compared. The models are flexible, and for that reason the process of successfully conducting operational synthesis needs to be iterative to correct such difficulties. However iterative approaches have a time penalty. In addition a concept exploration phase prior to concept validation would help identify many of the critical parameters and associated ranges and hence reduce the required number of iterations.

A goal for the practitioners of operational synthesis is to develop the process to a level of maturity that allows the stronger linking of models and simulations, not just by the use of a common scenario, but also through a formalisation of how the algorithms and data are used in each tool. Through the use of stronger linking of models, situations illustrated in Figure 8 could be avoided and the number of iterations through the tool set reduced.

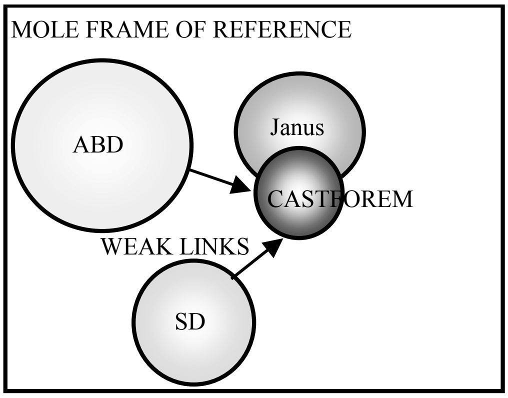

Figure 8: Weak linking of tools in an operational synthesis framework.

An approach currently being pursued by the ABD community is to develop simulation frameworks that can operate at increasingly higher levels of fidelity. That is, strong linking through the use of a single multi-resolution monolithic tool that can have algorithms turned on and off such that the tool can have multiple instantiations at different levels of fidelity. The potential disadvantage of this approach is that quite often the models and simulations are focussed on one type of problem, and as the modelling fidelity increases in that problem domain the tool's flexibility decreases. The authors are pursuing a different strategy, that of building a federation of models that can be tailored to the problem domain.

What currently makes ABDs attractive is that they can be applied across a wide range of problem domains, simply and quickly. The approach being perused by the authors is to continue to use ABDs as low fidelity tools in an operational synthesis framework to scope a wide problem domain to indicate high payoff analysis areas for higher fidelity tools. Our goal is to improve the strength of the links between ABDs and other tools beyond the current qualitative techniques demonstrated in this paper through the use of system frameworks in which to situate and relate each model and the subsequent results (Figure 9). The systems framework will have a very broad scope in order to cover the concept frame of reference and as a result possibly only a very limited analytical capability. Its main role will be to relate the models in such a way that the influences between critical parameters is understood and that any non-intersection of individual models can still be related to each other through the system framework. This approach can be viewed as a strengthening of the weakly linked approach to operational synthesis rather than the development of strongly linked monolithic tools.

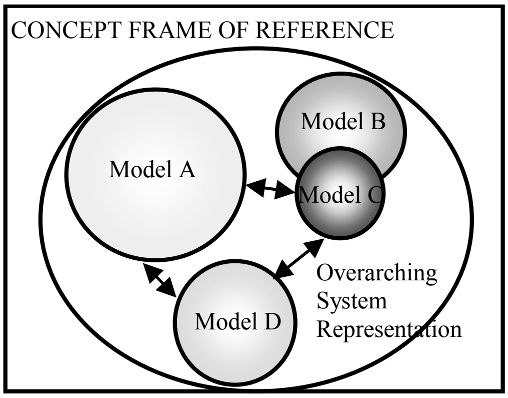

Figure 9: Overacrhing system representation to support weak linking of models.

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Appendix A: Concepts and Force Constructs

A.1. Manoeuvre Operations in the Littoral Environment (MOLE)

The MOLE concept is the keystone concept for Future Land Force Operations in DRI. This has been under development since 1999 and has been revised as a consequence of the Headline series of experiments. The HE00 Interim Report [6] described MOLE as the following.

"MOLE is defined as integrated sea–land–air operations involving forced entry from the sea and air within the littoral environment spanning northern Australia out to the inner arc. MOLE differs from an amphibious operation in that the latter is a relatively short-term joint event concluding with the breakout of land forces from a beachhead. Before and after a successful amphibious landing, air–sea and air–land operations are undertaken. By contrast, MOLE involves the continuous and coordinated employment of tri-Service assets in a common battlespace to achieve strategic outcomes. This distinction is depicted in Figure 10.

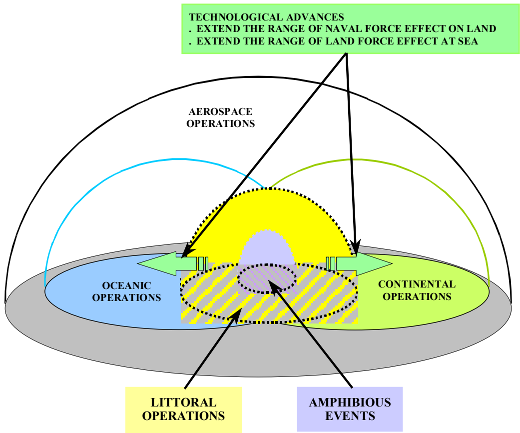

Figure 10: Manoeuvre Operations in the Littoral Environment.

Mounting, conducting and sustaining these operations will be very challenging for the ADF, particularly in the case of unilateral action. MOLE requires a new approach to providing credible, affordable and relevant forces to meet Australia's security needs." [6]

A.2. EXFOR1

The acknowledged requirement for EXFOR1 to conduct R&S functions and the deliberate designed similarity at the platform level, suggests that a generic high level cavalry unit could be used as a basis of description for analysis purposes (with airborne assets – helicopters and unmanned aerial vehicles, UAVs). Such a force can be said to have the capability to conduct two main types of function (according to SMA advice):

1. conduct reconnaissance (fight for information) and surveillance (gather information) for the force
2. offensive and defensive manoeuvre

An additional point from the analytic viewpoint is that a principle on which EXFOR1 was postulated was that it should be able to conduct heavy mechanised functions including deep manoeuvre against a mechanised force, if supported by appropriate situation awareness (hence the HE00 experiment involving an armoured OPFOR). The principle role of a mechanised armoured force is to close with and destroy the enemy.

From an analysis point of view the EXFOR1 capabilities and platform characteristics are an amalgam of the above. That is, EXFOR1 may be described as retaining the present day cavalry functions of conducting reconnaissance and surveillance and the capability to conduct offensive and defensive manoeuvre (such as flank security). The principle platform supporting this role is the light armoured vehicle (LAV). The deep operational requirement is supported in principle by long-range indirect fire, the armed reconnaissance helicopters (ARH) and UAVs organic to the battle group. The heavy mechanised function of 'destroy' is in principle provided by the ARH, indirect fire and LAV systems, providing a mixture of direct and indirect fires. The need to close with the enemy is, in principle, reduced by the enabling functions of enhanced SA throughout the force [6].

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